NACA

RESEARCH MEMORANDUM

COMPARISONS OF THE EFFECTIVENESS AND HINGE MOMENTS

OF ALL-MOVABLE DELTA AND FLAP-TYPE

CONTROLS ON VARIOUS WINGS

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SUMMARY

        A comparative evaluation has been made for all-movable delta and
flap-type controls on several wing plan forms. Comparison of these
experimental results from various test facilities indicates that half-
delta tip ailerons on unswept and swept wings produce greater rolling
effectiveness at supersonic speeds and less effectiveness at subsonic
speeds than the trailing-edge-flap type. For flap-type ailerons on a
highly swept thin wing, the optimum location of a partial-span aileron
was inboard because of both aerodynamic and aeroelastic considerations.
All-movable delta controls gave high effectiveness and low hinge moment,
in contrast with swept trailing-edge flaps of moderate effectiveness
and more hinge moment, and straight trailing-edge flaps were shown to
be associated with large hinge moments and decreasing flap effective-
ness with increasing Mach number.

INTRODUCTION

        Considerable aerodynamic data are available for flap-type ailerons
on outboard panels of wings at transonic and supersonic speeds. The
purpose of this paper is to summarize briefly some new type control
surfaces and further considerations for adequate rolling control effec-
tiveness. The data compared herein extend the study to the control
effectiveness of half-delta tip ailerons on straight and unswept wings,
effects of spanwise location of ailerons on a highly swept wing, effects
of torsional stiffness, and a summary of the hinge-moment problem for
various all-movable and flap-type control surfaces between Mach numbers
of 0.6 and 4.

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SYMBOLS

$\dfrac{pb/2V}{\delta}$ aileron-rolling-effectiveness parameter

C_{h_δ} rate of change of hinge-moment coefficient with deflection $(\partial C_h/\partial \delta)$

C_{h_α} rate of change of hinge-moment coefficient with angle of attack $(\partial C_h/\partial \alpha)$

C_{l_δ} rate of change of rolling-moment coefficient with aileron deflection $(\partial C_l/\partial \delta)$

S total area of the wing, square feet

S_a total area of ailerons, square feet

b total span of wing plus ailerons, feet

A aspect ratio (b^2/S)

λ taper ratio (Tip chord/Root chord)

t/c airfoil thickness ratio

Λ sweepback, degrees

c wing chord, feet

c_a aileron chord, feet

θ/m twist per unit moment at the midspan position, radians per inch-pound

M Mach number

R Reynolds number

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DISCUSSION

Half-Delta Tip Controls

As reported in references 1 and 2, half-delta tip ailerons on a $60°$ delta wing were shown to be a desirable high-speed roll-control surface. Therefore, tests were made by the free-roll rocket-propelled-model technique as reported in reference 3 to provide information on the application of half-delta tip ailerons to straight and swept wings.

Figure 1 shows the rolling-effectiveness parameter $\frac{pb/2V}{\delta}$ of a $56°$ half-delta tip aileron on a tapered straight wing. The quantity S_a/S is the ratio of the aileron area to the total area of the wing, which includes the aileron area. For these cases, the aileron area was 7 percent of the wing area and the span was taken to the tip of the aileron. The tip control was tested both as a reversed half-delta and a swept-back half-delta and, in each case, the hinge line was through the center of area. These results (fig. 1) show that the rolling effectiveness is less for the tapered straight wings than for the delta wing. These smaller values would be expected because the damping in roll is greater for the straight wings. The reversed half-delta shows slightly greater effectiveness than the sweptback half-delta. The "bumps" that occur for the delta wing between $M = 0.9$ and 1.0 are functions of the wing thickness and contour characteristics, not of the control.

Figure 2 shows the rolling effectiveness of these tip ailerons on a nontapered straight wing and a tapered sweptback wing. A comparison is made between a conventional half-span aileron (reference 4) and the tip aileron on similar straight wings. The tip aileron is not as effective at subsonic speeds on the basis of per unit deflection, but the tip half-delta may be used to deflections in the order of $30°$ to produce rolling effectiveness comparable to the flap type. The tip aileron is more effective at supersonic speeds and does not undergo any abrupt reductions in effectiveness at transonic speeds as does the flap type. For the application of the tip ailerons on a $45°$ sweptback tapered wing, lower rolling effectiveness is encountered at subsonic speeds; however, no reductions in effectiveness appear and the same level of effectiveness is maintained at subsonic and at supersonic speeds.

Location of Flap-Type Aileron on a Swept Wing

Considerable interest has been placed on the spanwise location of flap-type controls on sweptback wings. References 4 and 5 show that the effectiveness of outboard ailerons relative to that of the inboard ailerons was decreased as the wing sweepback was increased. Figure 3

shows that the spanwise position of the aileron markedly affects the
rolling power on a thin 63° sweptback tapered wing. These results are
from free-roll rocket-propelled-model tests. The inability of an out-
board quarter-span aileron to produce rolling moment and the fact that

roll reversal exists beyond $M = 1.5$ are shown. Note that $\dfrac{pb/2V}{\delta}$

reduces with increasing Mach number for the full-span aileron to values
near those for the inboard half-span aileron; this fact again shows
that the outboard sections of such a wing become relatively ineffective
at supersonic speeds. These results (fig. 3) are for a model wing of
solid duralumin, but the wing cannot be considered a rigid wing.
Therefore, the aggravating effects of aeroelasticity on rolling effec-
tiveness are present in these results. However, in the application of
this wing geometry to full-scale aircraft, solid-duralumin wings, or
wings of comparable stiffness to the model would not be expected; con-
sequently, the trend of the rolling power of these various ailerons is
indicated in figure 3. From these results, then, to apply flap-type
controls to highly swept thin wings the inboard ailerons appear to offer
the best solution to aerodynamic and aeroelastic effects at supersonic
speeds.

Torsional-Stiffness Effects on Rolling Effectiveness

The aeroelastic effects of varying wing torsional stiffness on
straight and swept wings have been determined using the rocket-propelled-
model technique as reported in reference 6. Figure 4 shows the effect
of some extremes in torsional stiffness on the rolling effectiveness of
a nontapered straight wing and a 45° nontapered swept wing. The tor-
sional stiffness is expressed by the values of θ/m, which is twist per
unit moment at the midspan position as determined by a couple applied
near the tip. Numerous stiffnesses were obtained by means of metal
plates of different sizes and materials set within the wing surface.
The two extremes of stiffness are shown for each plan form as the solid
line for the most rigid and the dashed line for the least rigid. Note
in figure 4 the marked effect of aeroelasticity on rolling effectiveness
on both the straight and swept wing, the least rigid wing in each case
encountering roll reversal. The 63° swept tapered wing shown in fig-
ure 3 had a torsional stiffness of $\dfrac{\theta}{m} = 0.85 \times 10^{-4}$ at the midspan loca-

tion even though made of solid duralumin; hence, it is apparent by com-
parison of θ/m values in figure 4 that the 63° swept wing would have
this aeroelastic problem. It must be remembered that the test condi-
tions for the models were different than they would be for a full-scale
supersonic aircraft in that the model data are for altitudes less than
15,000 feet, and the dynamic pressure varies from 740 pounds per square
foot at $M = 0.9$ to 2500 pounds per square foot at $M = 1.5$. Inasmuch

as various stiffnesses were tested (reference 6), the rolling effectiveness may be extrapolated to infinite stiffness, or $\frac{\theta}{m} = 0$, and these values were shown to be near to the solid curves shown in figure 4.

Hinge Moments of Various Controls

Experimental data on hinge moments have been obtained on various all-movable and flap-type controls between $M = 0.6$ and $M = 4$ by the techniques of transonic bump, supersonic tunnels, and rocket-propelled models. A preliminary evaluation of the hinge-moment problem of the various controls can now be made. Figure 5 shows the hinge-moment coefficient due to deflection C_{h_δ} as a function of Mach number for a collection of control surfaces. The comparison of the half-delta tip control on a $60°$ delta wing (reference 2) with a constant-chord flap-type control on a comparable delta wing (reference 7) shows a large difference in hinge moment due to deflection. The all-movable tip control allows for almost complete aerodynamic balance, whereas complete aerodynamic balancing of the flap type would be nearly impossible. Also shown are the hinge-moment characteristics of the canard control surfaces of a missile model (reference 8). These surfaces have the same balance characteristics as the tip aileron except as influenced by the presence of the large body. These results related to controls on the delta wing are from rocket-powered-model tests where the Reynolds numbers varied from 2×10^6 to 15×10^6, depending on the model and the Mach number range, except for the point at $M = 1.9$, which is from the Langley 9-by 12-inch supersonic blowdown tunnel at Reynolds number of 4×10^6 (reference 9).

A preliminary investigation by the rocket-model technique indicates (fig. 5) that sweeping a low-aspect-ratio ($A = 2.3$) thin wing $45°$ produced an aerodynamic balancing effect at transonic speeds. Also shown are the hinge-moment characteristics of an outboard aileron on a $40°$ swept wing. These data are from (1) tests made by the transonic-bump technique at $M = 1.1$ and $R = 1.1 \times 10^6$ (reference 10); (2) tests in the Langley 4- by 4-foot supersonic tunnel at $M = 1.4$ and 1.59 and $R \approx 0.6 \times 10^6$ (reference 11); and (3) tests in the Langley 9- by 12-inch supersonic blowdown tunnel at $M = 1.9$ and $R = 2.2 \times 10^6$ (reference 12). The curve in figure 5 with the circle symbols are the C_{h_δ} values for the basic conditions of the large trailing-edge angle associated with the circular-arc airfoil section. Thickening the trailing edge to give better aileron effectiveness makes the C_{h_δ} values (the square symbols) somewhat larger.

Hinge-moment characteristics are shown in figure 5 for a 30-percent-chord trailing-edge flap tested on circular-arc sections of 6- and 9-percent thickness in the Langley 9-inch supersonic tunnel at $M = 1.62$, 1.93, and 2.4 at $R \approx 1 \times 10^6$ (reference 13), and in the Langley $M = 4.0$, 9-inch blowdown jet at $M = 4.04$ at $R = 5 \times 10^6$. These data are two-dimensional data gained by integration of the pressure distribution over the flap. Note the decreasing values of C_{h_δ} with increasing Mach number. An interesting point may be noted in that it appears that the C_{h_δ} values for the flap on the $60°$ delta wing may be faired logically into the values for the flap on the straight wing.

It appears, then, that the controls may be classed into three groups: (1) all-movable deltas with very low hinge moments, (2) swept trailing-edge flaps where the sweep may aid in reducing hinge moments at transonic speeds, and (3) straight trailing-edge flaps associated with large hinge moments.

In figure 6 is shown the hinge-moment coefficient due to angle of attack C_{h_α} of some of these controls. The C_{h_α} values are of the same order of magnitude as the C_{h_δ} values, therefore of equal importance. Again the excellent aerodynamic balancing characteristics of the delta controls are shown, the effects of sweep and trailing edge contour, and the large C_{h_α} values associated with the straight trailing-edge flap. The hinge moments may be decreasing with Mach number for the trailing-edge flap, but also the effectiveness is decreasing as shown in reference 1. This decrease is reasonable because, as the load comes off this type of flap (reference 13), the effectiveness reduces also.

In an attempt to evaluate the use of the three types of controls, that is, all-movable, swept trailing-edge flap, and straight trailing-edge flap, the control effectiveness produced must be considered, as well as the hinge moment to overcome. Therefore, the parameter of the ratio of the control effectiveness to the control hinge moment due to deflection was arbitrarily chosen for evaluation of a rolling control. This parameter $C_{l_\delta}/C_{h_\delta}$ is shown in figure 7 for the three configurations. The sign of $C_{l_\delta}/C_{h_\delta}$ was not considered, only the magnitude of the number is considered. A large number would then indicate high effectiveness for a given hinge moment, whereas a small number would indicate low effectiveness for a given hinge moment. This parameter is valid where no appreciable rolling velocity is present, that is, for an automatic system which prevents large roll velocities. Another way of looking at this parameter is the reciprocal of the ratio, or $C_{h_\delta}/C_{l_\delta}$, where a large number would indicate excessive amounts of servo-system

power for a given effectiveness. For the half-delta tip control, due
to its excellent balance characteristics, large ratios of control effec-
tiveness to hinge moment are reached with increasing Mach number. Also,
as shown previously, this control has good effectiveness at supersonic
speeds. A swept trailing-edge control is as good as the tip control at
subsonic speeds but suffers reduced effectiveness and slightly increasing
hinge moments as the Mach number increases; therefore, the ratio of C_{l_δ}
to C_{h_δ} falls off, indicating an inferior supersonic control. The
straight trailing-edge flap has the lowest ratio of C_{l_δ} to C_{h_δ} due
to the large hinge moments even though the effectiveness is adequate.
These low ratios indicate a control in which the servo-system power
required would be large for amount of rolling moment produced. For
this flap type on a delta wing, control-effectiveness data were avail-
able to near $M = 2.0$ but hinge moments were not. Therefore, the
dashed portion is an extrapolation by using the existing C_{l_δ} values
and dividing by the two-dimensional C_{h_δ} values from the straight
trailing-edge flap on the straight wing.

CONCLUSIONS

Comparison of recent experimental results for various controls on
several wing plan forms indicated that half-delta tip ailerons on
unswept and swept wings may produce greater rolling effectiveness at
supersonic speeds and less effectiveness at subsonic speeds than the
trailing-edge-flap type. For flap-type ailerons on a highly swept thin
wing, the optimum location of a partial-span aileron was inboard because
of both aerodynamic and aeroelastic considerations. All-movable delta
controls gave high effectiveness and low hinge moment, in contrast with
swept trailing-edge flaps of moderate effectiveness and more hinge
moment, and straight trailing-edge flaps were shown to be associated
with large hinge moments and decreasing flap effectiveness with
increasing Mach number.

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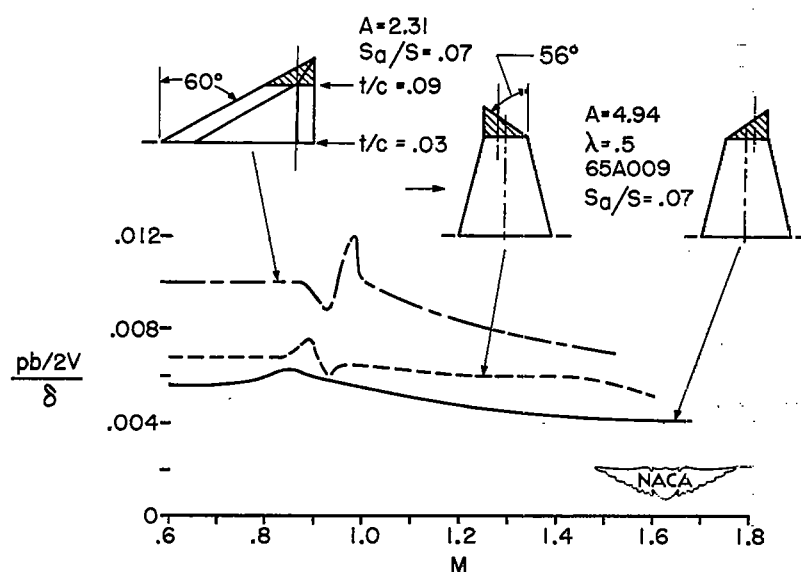
Figure 1.- Rolling effectiveness of a half-delta tip aileron on a tapered straight wing.
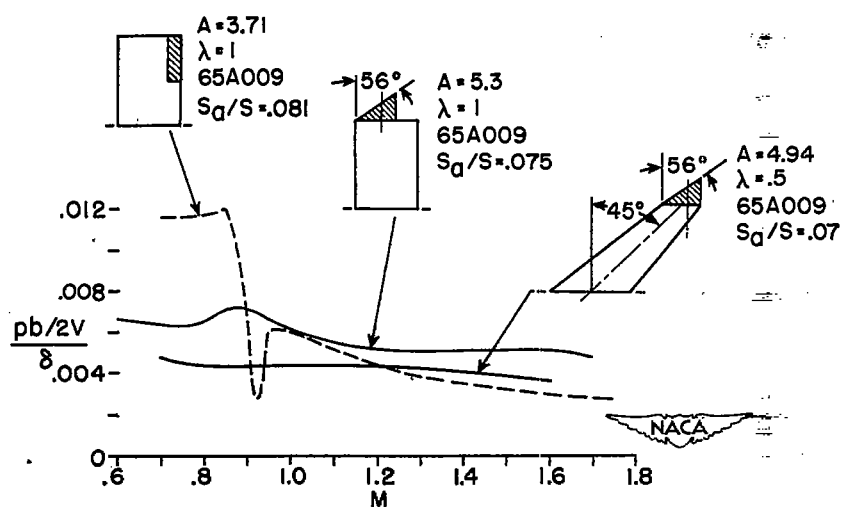

Figure 2.- Rolling effectiveness of a half-delta tip aileron on a straight wing and a sweptback tapered wing.
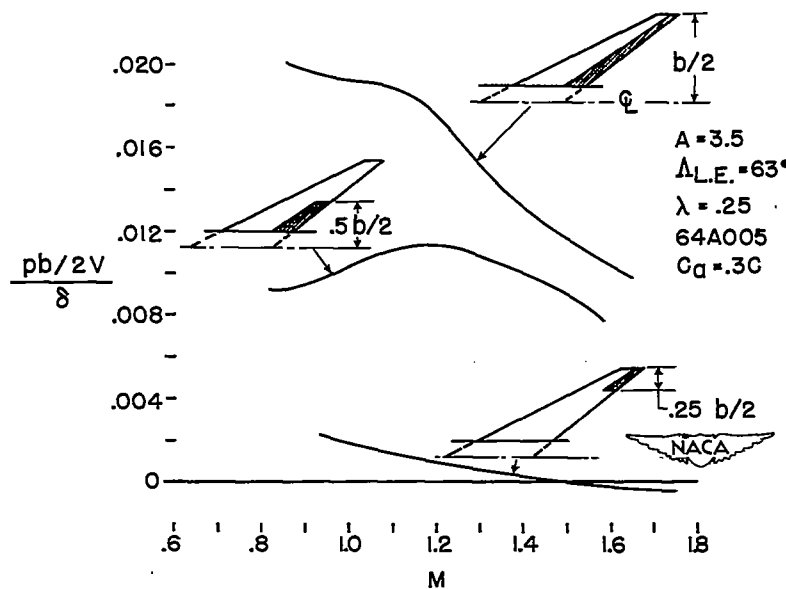
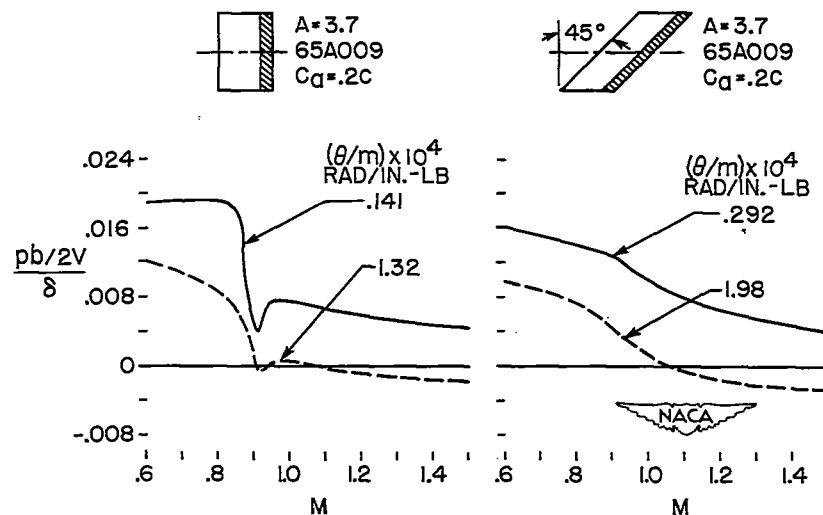Figure 3.- Effect of spanwise location of aileron on rolling effectiveness of a thin sweptback wing.

Figure 4.- Effect of torsional stiffness on the rolling effectiveness of flap-type ailerons on a straight and a swept wing.
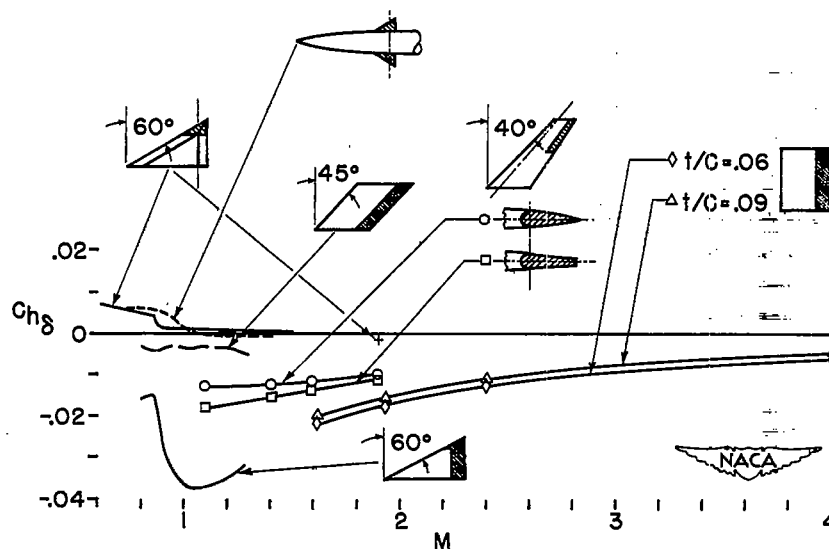
Figure 5.- Hinge moment due to deflection for a collection of control
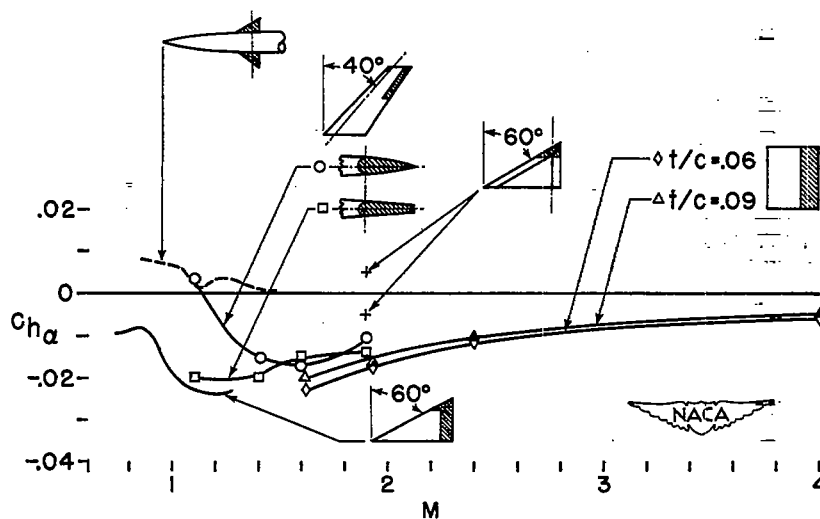surfaces. Hinge moment and deflection measured perpendicular to
hinge line.

Figure 6.- Hinge moment due to angle of attack for a collection of
control surfaces. Hinge moment and deflection measured perpendicular
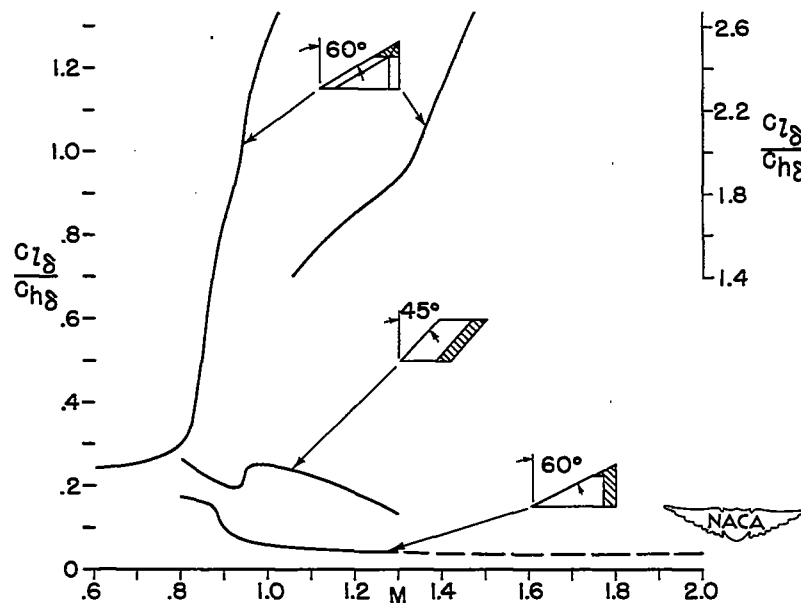to hinge line.

Figure 7.- Ratio of roll control effectiveness to hinge moment due to
   deflection for the half-delta tip aileron, swept trailing-edge flap,
   and the straight trailing-edge flap.